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An Assessment of the Accuracy of PPP in Remote Areas in Oman

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Key words: GNSS, PPP, Oman Survey Infrastructure

SUMMARY

Traditionally, high accuracy Global Navigation Satellite Systems (GNSS) positioning has involved differential techniques. Such techniques significantly reduce or eliminate inherent biases in the GNSS measurement by referencing simultaneous measurements to one or more known reference stations. On a national scale, these differential techniques rely heavily on a costly spatial infrastructure of accurately known points usually occupied by Continually Operating Reference Stations (CORS). In recent years, the development of Precise Point Positioning (PPP) techniques have been shown to reduce many of the inherent observation errors and biases in GNSS solutions which eliminate the need for a ground based reference station. Such techniques may provide sufficient accuracy when surveying in remote locations where CORS infrastructure are not suitable.

To assess the suitability of PPP as a viable positioning technique, fifteen known control points in remote areas of Oman were observed by the National Survey Authority field survey team in 2014. Each station was observed for two sessions (1- and 2-hours in duration) and the observed data sent to three PPP online services - Trimble RTX, CSRS and AUSPOS. The results were compiled and analyzed to evaluate the accuracy of PPP in Oman.

Results indicated a bias in Easting across all sites and although some variability in the results was found, there was no significant difference in results between the three online service providers. Differences in the 3D position of both the 1- and 2-hour sessions of 33% of the samples were found to be approximately 50mm. Thus it has been shown that PPP can provide a positioning solution and be adopted for medium-accuracy positioning purposes in remote areas.

An Assessment of the Accuracy of PPP in Remote Areas in Oman

Rashid AL ALAWI, Sultanate of Oman, Audrey MARTIN, Ireland

1. INTRODUCTION

The National Survey Authority (NSA) of the Sultanate of Oman is currently developing a new national surveying positioning infrastructure which will establish a CORS network across the most populated regions of the country. However, as Oman extends over an area of 309,000 km^2, with large uninhabited areas of mountains and deserts, it is not feasible or practical to establish a high density CORS network in these areas. Thus, the use of PPP solutions delivered from a number of online PPP services as a potential alternative GNSS positioning solution for the remote areas of Oman was investigated in this study.

1.1 Omans Survey Infrastructure

The development of Oman's surveying and mapping infrastructure began in 1954 with the Fahud Geodetic Datum established by Petroleum Development Omans. In 1979, a Doppler satellite campaign was carried out and 42 control stations in the Fahud Datum network were occupied, resulting in coordinate values with respect to the WGS72 system. In 1996, the GPS satellite datum of WGS84 defined by the GRS80 ellipsoid, which is closely aligned with the International Earth Rotation Service (IERS) Terrestrial Reference Frame (ITRF94), was adopted.

A GPS primary survey infrastructure, known as the Cooperative International GPS Tracking Network (CIGNET) WGS84, established by NSA, was realized in Oman in 1994. It is comprised of seven GPS primary stations observed for 60 hours. These seven stations are distributed across the whole of Oman (Figure 1) and the network is known as The Sultanate of Oman WGS84 stations. In 1993, the First Order GPS Network was established by NSA. It is comprised of 79 GPS control stations which were each observed for 24 hours. Connection was made to the seven earlier GPS-surveyed campaign stations in the WGS84 (ITRF89) frame system. The Second Order GPS stations network for Oman is comprised of 494 stations, which were established progressively by NSA until 2010 (Figure 1). These stations, of which over 90% are benchmarks, were observed for 2-4 hours depending on the baseline length (NSA, 2014).

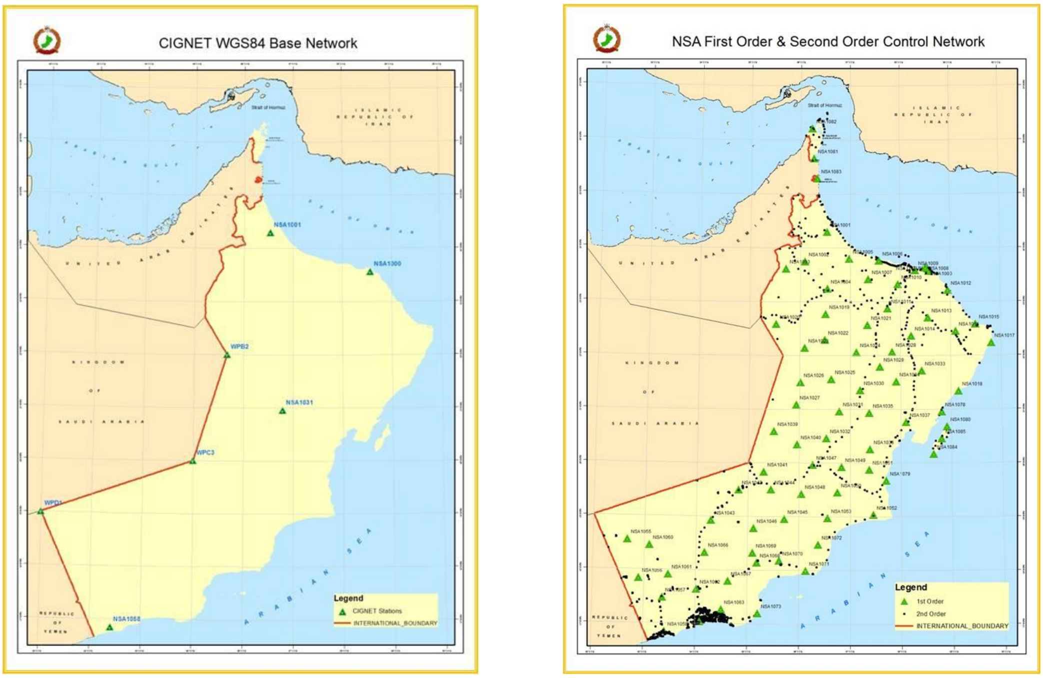


Figure 1: CIGNET WGS84 Base Network and the First and second order GPS station in Oman (NSA, 2014)

In 2014, a new geocentric datum - the Oman National Geodetic Datum 2014 (ONGD14) based on the latest global ITRF2008 frame solution was adopted. This was realized by 20 geodetic control points (Figure 2) which included the seven primary stations from CIGNET and 13 First Order GPS stations, and connected to almost 50 International GNSS Service (IGS) sites. The resulting coordinates for all 20 geodetic control points were estimated in the ITRF2008 epoch 2013 and the transformation parameters between ITRF2008@2013 and ITRF89 was calculated (NSA, 2014). These parameters are given in Table 1.

Figure 2: NSA First Order GPS Field Campaign (NSA, 2014)

Table 1: Seven transformation parameter from ONGD14 to WGS84 (ITRF89) (NSA, 2014)

Parameters	Values
Translation in X	819.0 mm
Translation in Y	-576.2 mm
Translation in Z	-1644.6 mm
Rotation around X-axis	0° 0' 0.00378"
Rotation around Y-axis	0° 0' 0.03317"
Rotation around Z-axis	- 0° 0' 0.00318"
Scale factor	0.0693

1.2 Precise Point Positioning (PPP)

The PPP autonomous positioning technique uses a single GNSS receiver without the need for differential corrections from reference stations. Thus PPP solutions are provided in a dynamic, global reference frame without the typical local distortions related to differential positioning techniques. However, accurate PPP solutions still require corrections such as satellite orbit and clock corrections, satellite antenna phase centre corrections, phase wind-up corrections, solid earth tide corrections and ocean loading corrections which must be sourced (Grinter & Roberts 2013). Data pertaining to precise satellite orbits and clock corrections can be accessed from suppliers such as the International GNSS Service IGS. Table 2 lists some of the products IGS currently provide.

Table 2: Precise GNSS satellite orbits and clock corrections provided by IGS (IGS, 2013)

Product	Parameter	Accuracy	Latency
Broadcast	Orbit Clock	100 cm ~ 5 ns	Real Time
Ultra rapid (predicted)	Orbit Clock	10 cm ~ 5 ns	Real Time
Ultra Rapid (estimated)	Orbit Clock	< 5 cm ~ 2 ns	3-9hrs
Rapid (estimated)	Orbit Clock	< 5 cm 0.1 ns	17-41 hrs
Final (estimated)	Orbit Clock	< 5 cm < 0.1 ns	12-18 days

Despite several advantages, PPP is also subject to a number of disadvantages, the most important being the long observation times required. To achieve centimetre-level positioning accuracy 20 minutes or more are necessary for the integer ambiguity solution to converge (Rizos *et al*., 2012). Longer occupation times will generally result in more accurate results but shorter observation times will restrict the use of PPP for real-time applications.

In recent years, a number of PPP post-processing software systems including BERNESE GIPSY-Oasis II, RTKLIB and GPSTK have been developed by government agencies, universities and industries. Some of these are open source programmes which permit some user interaction with the data used in the solution. In addition, a number of free to use post-processing services are currently available. These services are available to users to upload RINEX data to generate coordinate solutions for the static or kinematic GNSS receiver's position.

2. METHODOLOGY

To assess if PPP is a suitable an alternative GNSS positioning techniques for remote areas in Oman 15 known control points from within the national Second Order geodetic network (Figure 2) were observed by the NSA field survey team. Each station was observed for two sessions (one- and two-hours) to determine also if a significant increase in accuracy could be achieved by increasing the observation time. The observed RINEX data was sent to three PPP service sites (Trimble RTX, CSRS and AUSPOS) for comparative purposes and the resulting data analyzed to evaluate the accuracy of PPP in Oman. Figure 3 graphically depicts the methodology adopted.

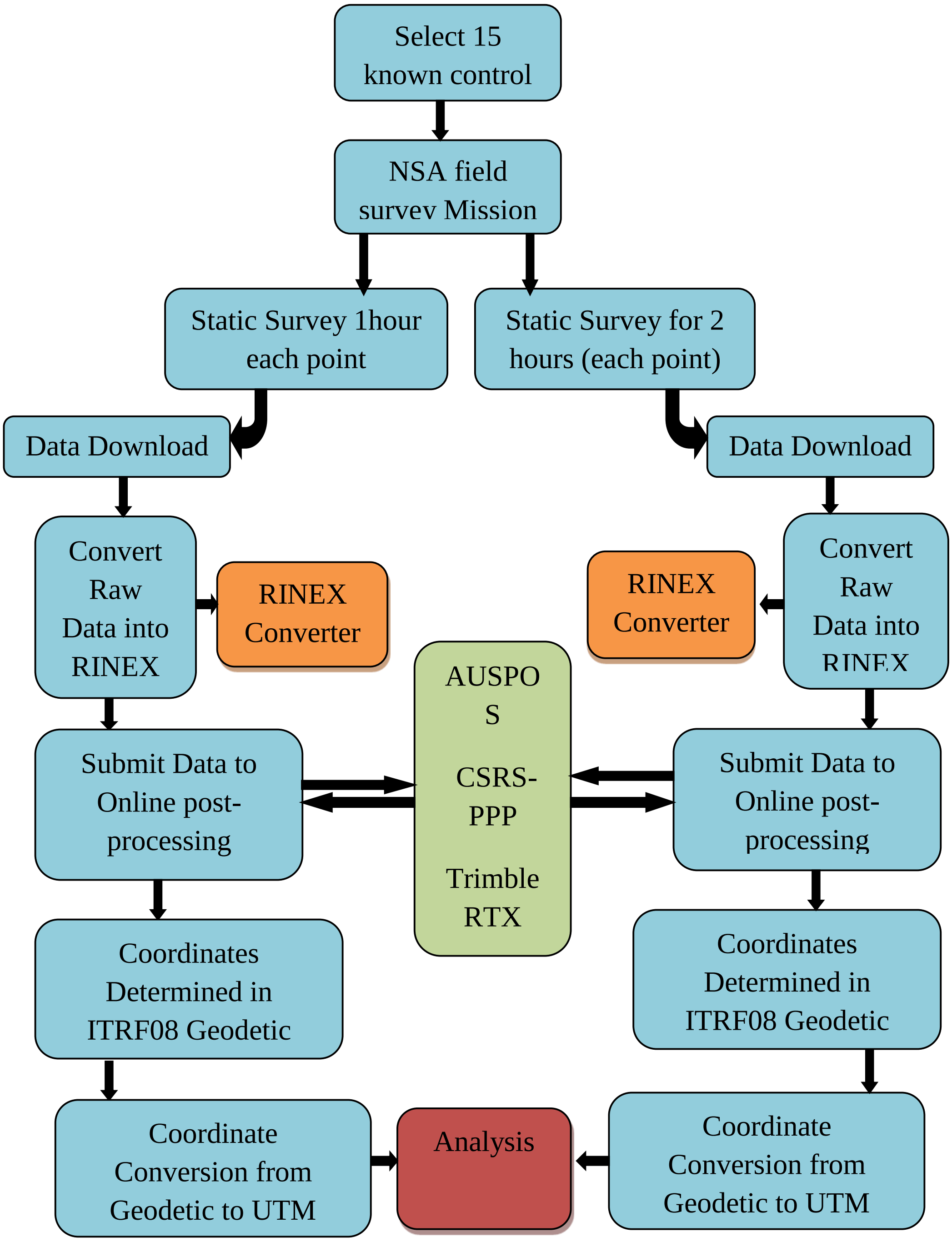


Figure 3: Methodology Flowchart

The field survey was conducted between 27th April and 13th May, 2014. All 15 control points were located in open sky sites and had quoted accuracy of < 1 ppm/km in the horizontal and < 3 ppm/km in the vertical (NSA, 2014). Mission planning was undertaken prior to each survey day to ensure optimum satellite geometry. A Trimble 5700 receiver was used for all observations. The elevation cut-off angle was fixed at 15°, and the observation data interval time was fixed at 15 seconds. The antenna height and the observation time were recorded in booking sheets. Figure 4 indicates the location of each of the control points surveyed.

Figure 4: Locations of 15 control stations
(*source: Google maps, 2014*)

2.1 Converting and submitting online data in RINEX format

The Trimble RINEX converter software was used to convert the data into RINEX format. Three ASCII file types resulted: (1) observation data files; (2) navigation message files; and (3) meteorological data files. Some editing of data observations was required before converting the data file to the RINEX format to correct for antenna specific information at each point. Seven web PPP services were selected for comparison however, data was initially accepted by only three providers: AUSPOS, APPS and CSRS. Magic GNSS and Trimble RTX subsequently also accepted the data. The GAPS and OPUS services provided no rejection information. For correlation purposes it was decided to compare the results from the following three service providers: Trimble RTX, CSRS and AUSPOS.

2.2 Coordinate Conversion

Each online post-processing service (Trimble RTX, CSRS and AUSPOS) provided solutions via email within two minutes in ITRF08 at the current epoch. Coordinates were provided in geodetic (latitude and longitude) and cartesian (X, Y, Z) format. Since the geocentric datum of Oman (ONGD 14) is based on the latest global ITRF2008 system at epoch 2013, the coordinates of the control points occupied in this study and the service results coordinates were in the same coordinate system. Thus, there was no need to undertake a transformation. However, a conversion was required to UTM (Universal Transverse Mercator Zone 40). For this purpose the NSA coordinate transformation facility (Figure 5) was used.

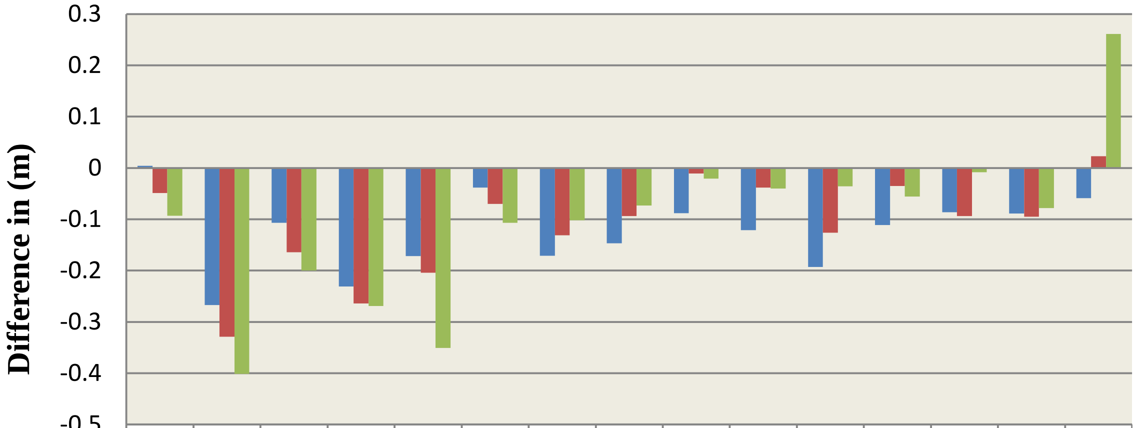
Figure 5: Coordinate transformation program developed by NSA

3. RESULTS AND ANALYSIS

Final coordinates as determined by the three online services: Trimble RTX, CSRS, and AUSPOS for each of the 15 control sites were individually analysed. For the purposes of this paper these results are directly compared graphically for both the one- and two-hour measurement sessions

3.1 One-hour Observation Results

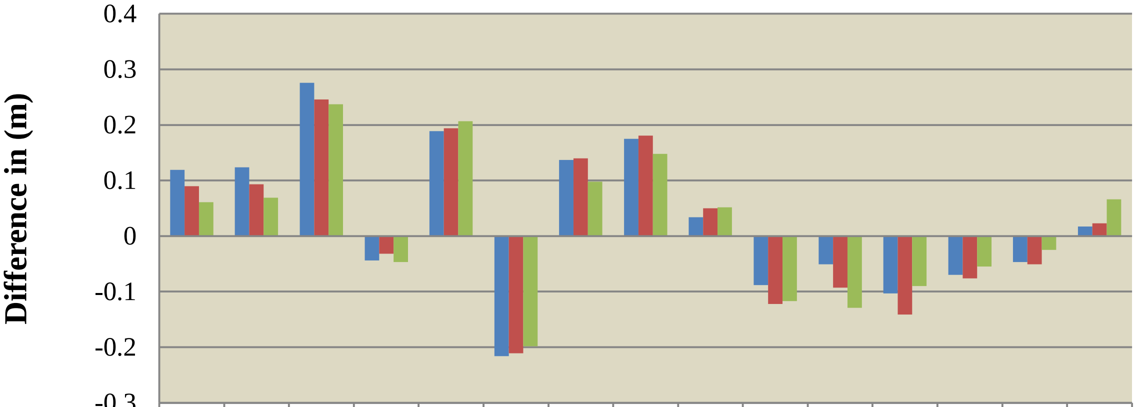
Figure 6 illustrates the accuracy obtained in the Easting from the three PPP online services using one-hour data observations. From Figure 6 it is evident that, while the results obtained by Trimble RTX online service were more accurate than the other PPP online services at seven sites, AUSPOS scored better for accuracy in five sites and CSRS in three sites. It can also be noted that all the results from the three providers agreed in the direction of the differences (i.e. negative values) in all but one site, station 15. This similarity in results indicates a possible systemmatic effect, which may be due to a shift to the east in those stations caused by tetonic movement. This requires further investigation possibly through re-observing and processing the test sites using the 20 geodetic control points (Figure 2) which originally connected to the ITRF08 coordinate frame system.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Δ E Trimble	0.004	-0.267	-0.107	-0.231	-0.172	-0.038	-0.171	-0.147	-0.088	-0.121	-0.193	-0.111	-0.086	-0.089	-0.059
Δ E CSRS	-0.049	-0.329	-0.164	-0.264	-0.204	-0.07	-0.131	-0.094	-0.011	-0.038	-0.126	-0.035	-0.094	-0.095	0.023
Δ E AUSPOS	-0.093	-0.401	-0.2	-0.269	-0.351	-0.107	-0.102	-0.073	-0.021	-0.04	-0.036	-0.056	-0.008	-0.078	0.261

Figure 6: Easting accuracy obtained using three PPP service (one-hour data observation)

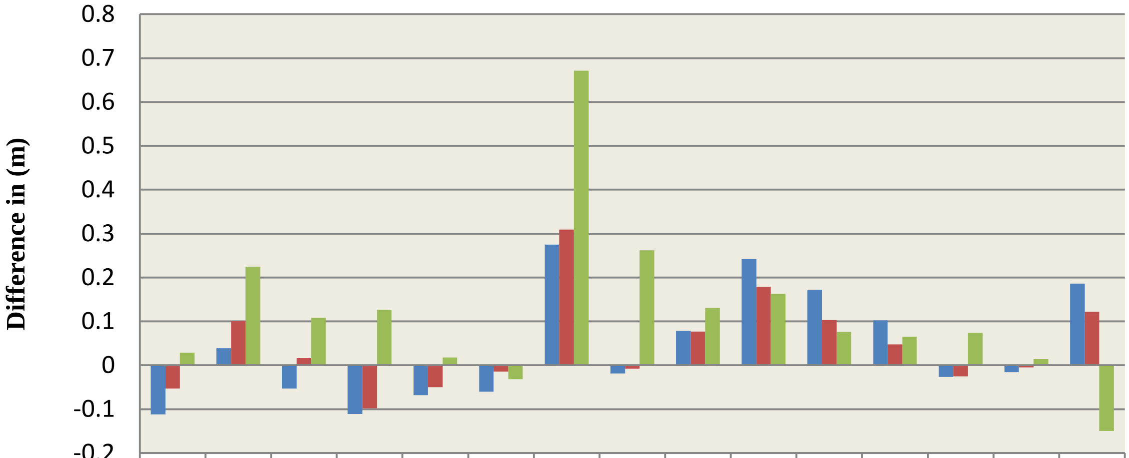
A comparison of the Northing accuracy obtained by the three PPP online services is illustrated in Figure 7. Here it can be seen that, while the results obtained from the AUSPOS online service were more accurate than the other two online services at nine sites, the Trimble RTX results more accurate than the other two providers at five sites, while CSRS proved best at one site. The differences' direction and values were similar at all sites.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Δ N Trimble	0.119	0.124	0.276	-0.044	0.189	-0.216	0.137	0.175	0.034	-0.088	-0.051	-0.103	-0.07	-0.047	0.017
Δ N CSRS	0.09	0.093	0.246	-0.032	0.194	-0.211	0.14	0.181	0.05	-0.122	-0.093	-0.141	-0.076	-0.051	0.023
Δ N AUSPOS	0.061	0.069	0.237	-0.047	0.207	-0.198	0.098	0.148	0.052	-0.117	-0.129	-0.09	-0.055	-0.025	0.066

Figure 7: Northing accuracy obtained via three PPP online services (one-hour data observation)

The accuracy in the Height returned from the three PPP online services are graphically illustrated in Figure 8. Here it can be seen that, while the results obtained by CSRS online services were more accurate at eight sites, the AUSPOS results were more accurate at five sites and the Trimble at one site. It should also be noted that the AUSPOS height results were the least accurate, recording the poorest results at eight stations, and by a factor of more than two at stations 2, 7 and 8.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Δ H Trimble	-0.112	0.039	-0.053	-0.111	-0.068	-0.06	0.275	-0.019	0.078	0.242	0.172	0.102	-0.027	-0.016	0.186
Δ HCSRS	-0.053	0.101	0.016	-0.098	-0.05	-0.014	0.309	-0.008	0.077	0.179	0.103	0.048	-0.025	-0.005	0.122
Δ HAUSPOS	0.029	0.225	0.108	0.126	0.018	-0.032	0.671	0.262	0.131	0.163	0.076	0.065	0.074	0.014	-0.15

Figure 8: The height accuracy obtained via three PPP online services (one-hour data observation)

On comparing the results of the one-hour observations from three online services it was found that, while the lowest differences in the Easting (4mm) and in the Northing (14mm) were achieved using the Trimble RTX service, the lowest difference in Height was achieved by the CSRS services. The largest difference in the Easting (401mm) and in Height (671mm) resulted from using the AUSPOS service. Conversely, the Trimble RTX online service produced the largest difference in the Northing (276mm). The maximum and minimum differences for each PPP service provider are given in Table 3.

Table 3: The minimum and maximum differences achieved using one-hour PPP online services

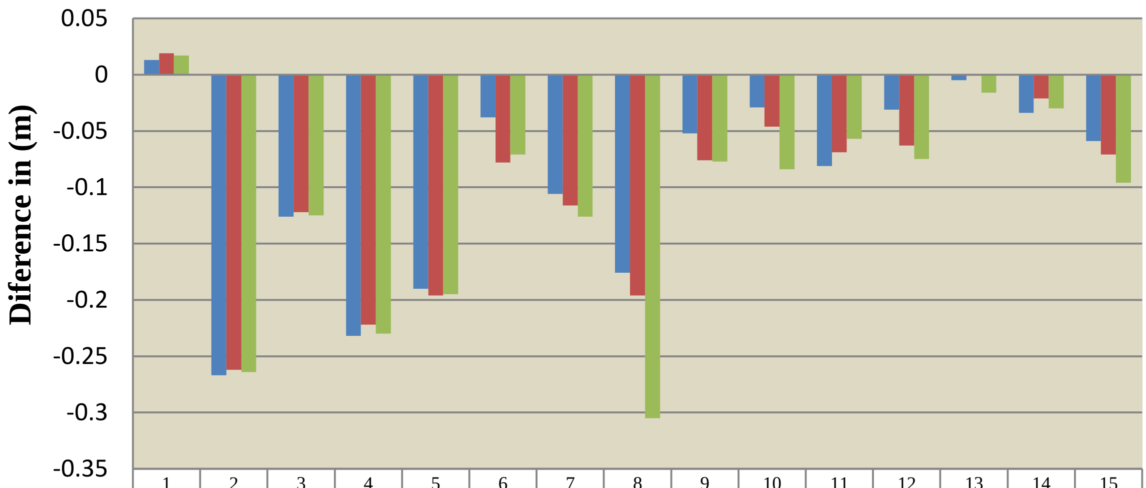
PPP online service	Difference (mm)	Easting	Northing	Height
Trimble RTX	Min	4	14	16
	Max	267	276	275
CSRS	Min	11	23	5
	Max	264	246	309
AUSPOS	Min	8	25	14
	Max	401	237	671

When using the Trimble RTX solution it was found that the differences between known values and the PPP results in the one-hour observations ranged from 4 to 267, 14 to 276 and 16 to 275 mm in Easting, Northing and Height, respectively (Table 3). The average differences were 131, 112 and 104 mm in the Easting, Northing and Height, respectively.

The results of the one-hour observation obtained by CSRS online services for all sites in the Easting ranged from 11 to 264 mm, from 23 to 246 mm in the Northing and from 5 to 309 mm in the height (Table 3). The differences resulting from one-hour observation using the AUSPOS online service ranged from 8 to 401mm, 25 to 237 mm and 14 to 671 mm in the Easting, Northing and Height, respectively (Table 3). Meanwhile, the average difference in the Easting was 140mm; in the Northing, it was 107mm; and in the Height was 143mm.

3.2 Two-hour observation results

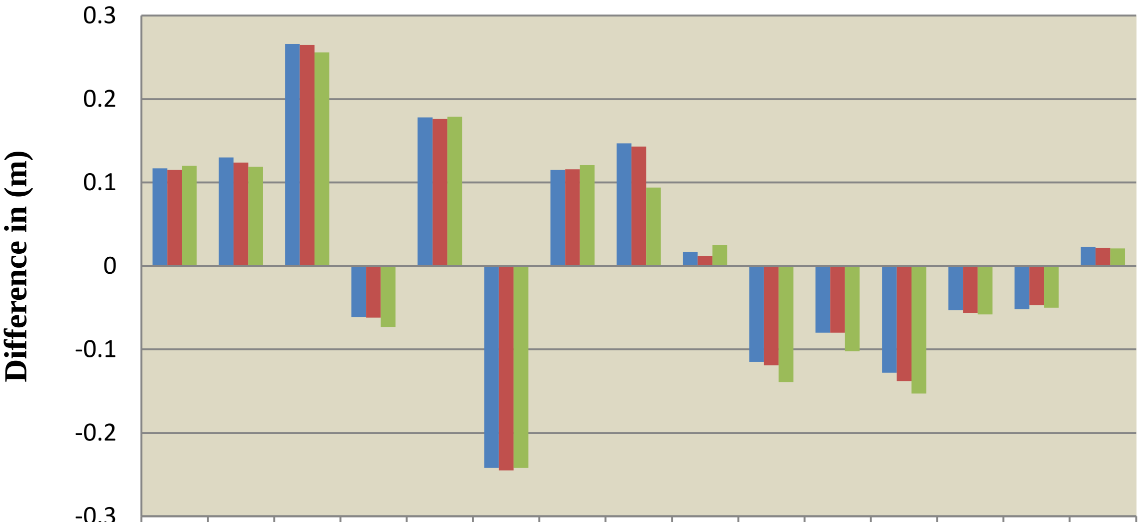
Figure 9 depicts the accuracy obtained in the Easting from the three PPP online services using two-hour data observations. It shows that, while the accuracy of the Trimble RTX online service was higher than the other two online services at eight sites, the CSRS resulted in better accuracy at five sites, and AUSPOS at only one site. A similar trend can be recognized in the Easting difference results noted with one-hour observation. The differences in the Easting obtained from the three online services are in the negative direction at all sites, except one, in this case at station 1 rather than station 15 as was evident in the one hour session. As with the one-hour observation results this apparent systematic bias requires further measurement and analysis to determine the root of the issues affecting the Easting coordinate.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Δ E Trimble	0.013	-0.267	-0.126	-0.232	-0.19	-0.038	-0.106	-0.176	-0.052	-0.029	-0.081	-0.031	-0.005	-0.034	-0.059
Δ E CSRS	0.019	-0.262	-0.122	-0.222	-0.196	-0.078	-0.116	-0.196	-0.076	-0.046	-0.069	-0.063	-0.001	-0.021	-0.071
Δ E Auspos	0.017	-0.264	-0.125	-0.23	-0.195	-0.071	-0.126	-0.305	-0.077	-0.084	-0.057	-0.075	-0.016	-0.03	-0.096

Figure 9: Easting accuracy obtained via the three PPP online services (two-hour data observation)

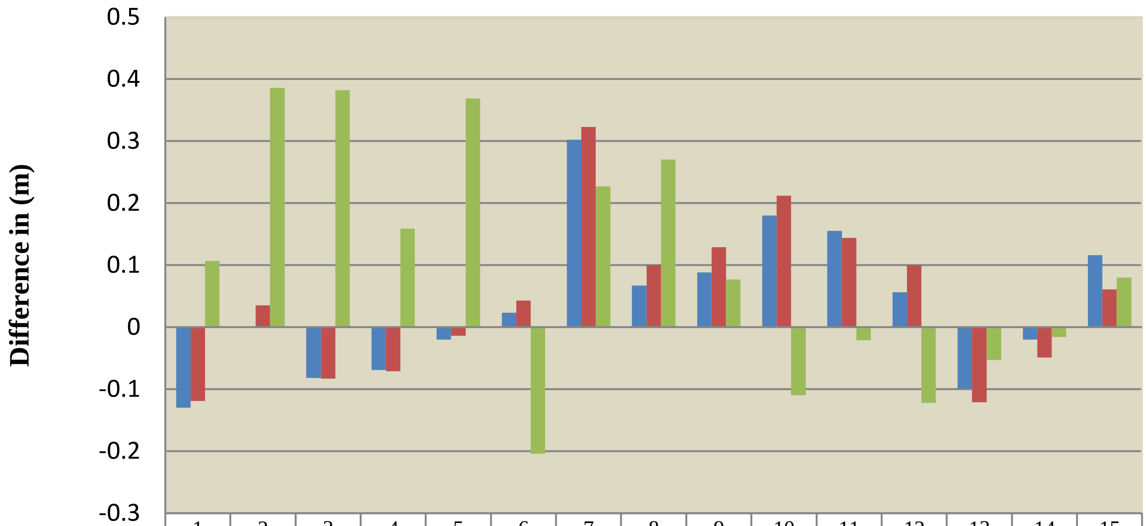
In Figure 10 a comparison of the Northing difference achieved using the three PPP online services is shown. This figure shows the similarity in the accuracy obtained by all three PPP services, negligible differences at each site are evident. It also shows that each of the online PPP solution provided achieved the best results at five sites.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Δ N Trimble	0.117	0.13	0.266	-0.061	0.178	-0.242	0.115	0.147	0.017	-0.115	-0.08	-0.128	-0.053	-0.052	0.023
Δ N CSRS	0.115	0.124	0.265	-0.062	0.176	-0.245	0.116	0.143	0.012	-0.119	-0.08	-0.138	-0.056	-0.047	0.022
Δ N AUSPOS	0.12	0.119	0.256	-0.073	0.179	-0.242	0.121	0.094	0.025	-0.139	-0.102	-0.153	-0.058	-0.05	0.021

Figure 10: Northing accuracy obtained via the three PPP online services using two-hour data observation.

The accuracy of the Height values for the two-hour data sessions from the three PPP online services are demonstrated in Figure 11. Here it is noted that, while the Trimble and CSRS results were similar at most of the sites, with slight differences, the AUSPOS results were very different to the other two services. The height difference values returned by the AUSPOS service were significantly different at test sites 2, 3, 5 and 6, yet the results obtained using AUSPOS were the best at seven sites.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Δ H Trimble	-0.13	0	-0.082	-0.069	-0.02	0.023	0.302	0.067	0.088	0.18	0.155	0.056	-0.099	-0.02	0.116
Δ H CSRS	-0.119	0.035	-0.083	-0.071	-0.014	0.043	0.323	0.1	0.129	0.212	0.144	0.1	-0.121	-0.049	0.061
Δ H AUSPOS	0.107	0.386	0.382	0.159	0.369	-0.204	0.227	0.270	0.077	-0.110	-0.021	-0.122	-0.053	-0.016	0.080

Figure 111: Height accuracy obtained via the three PPP online services using two-hour data

In the two hours' observations, the difference between the true coordinates and the PPP results obtained from Trimble RTX ranged from 5 to 267 mm in the Easting, from 17 to 266 mm in the Northing, and from 0 to 302 mm in the Height. The differences obtained by CSRS ranged from 1 to 262 mm in the Easting, from 12 to 265 mm in the Northing and from 14 to 323 mm in the Height. The differences obtained by AUSPOS, meanwhile, ranged from 16 to 305 mm in the Easting, from 21 to 256 mm in the Northing and from 9 to 284 mm in the Height.

From these findings, it should be noted that, when using two hours' observations, the smallest differences in the Easting (1mm) and the Northing (12mm) were obtained by the CSRS, while, in the Height (9mm) it was obtained using AUSPOS. Conversely, the largest difference in the Easting (305mm) resulted from using AUSPOS; in the Northing (266mm), resulted from Trimble RTX; and in the Height (323mm) it was associated with the CSRS, refer to Table 4.

Table 4: The minimum and maximum differences achieved using two-hour PPP online services.

PPP online service	Difference (mm)	Easting	Northing	Height
Trimble RTX	Min	5	17	0
	Max	267	266	302
CSRS	Min	1	12	14
	Max	262	265	323
AUSPOS	Min	16	21	9
	Max	305	256	284

From the results obtained it is recognized that a two-hour observation generally provides slightly better coordinates than one-hour observation. Table 5 illustrates the average differences obtained in the Easting, Northing and Height in both one- and two-hour observations.

Table 5: The average differences in mm obtained from one- and two-hour observations

PPP online service	Observation Time	Easting	Northing	Height
Trimble RTX	1-hour	131	112	104
	2-hours	96	115	94
CSRS	1-hour	115	116	081
	2-hours	104	115	107
AUSPOS	1-hour	140	107	143
	2-hours	117	116	66

Overall, variability in the results across the 15 sites between all three PPP services was recognized. Nevertheless, it should be noted that the differences in the 3D position of 33% of the samples were approximately 50 mm in 1-hour and 2-hour results across all three services. This result is somewhat similar to the findings reported by EL-Hattab (2014), who noted that accuracy to less than one centimetre can be achieved after approximately seven hours' observation.

4. CONCLUSION

To determine if the PPP technique represented a suitable alternative to relative GNSS positioning across remote areas of Oman two sets of PPP GNSS data involving 15 control points were observed. The 3D positional results obtained from three PPP online services were compared to the true coordinates of the 15 control points and it was found that 33% of the differences in 3D positioning across the 15 sites were within an accuracy level of approximately 50 mm. Thus it can be stated that the PPP method could be used with confidence for medium-accuracy positioning purposes, such as map production to small and medium scales.

The results obtained from the 3 PPP service providers indicated a disturbing bias in Easting coordinate across all but one site from both observation sessions. This indicates a systematic effect which requires further GNSS observation and analysis with respect to primary and/or first order control. Overall no significant difference between the 3 PPP online providers – Trimble RTX, CSRS and AUSPOS was found to exist.

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BIOGRAPHICAL NOTES

Rashid Al Alawi is the Project officer at the National Survey Authority (NSA) - Sultanate of Oman. He graduated with an MSc in Geospatial Engineering from the School of Surveying and Construction Management in the Dublin Institute of Technology in 2014. Rashid has worked in the (NSA) as a field survey team leader in the period from 1998 until 2010. Subsequently Rashid was promoted to the training officer in charge until 2013.

Dr. Audrey Martin is the Chair of the MSc in Geospatial Engineering programme, she lecturers in the Spatial Information Sciences in the Dublin Institute of Technology. Audreys' area of expertise is Global Navigation Satellite Systems (GNSS) and Geomatics pedagogy. Audrey held the DIT Teaching and Learning Fellowship in 2011 and was jointly awarded the 2010 Teaching Excellence Award in the College of Engineering and Built Environment. Audrey supervised the two most recent student winners of the Trimble Dimensions Student paper competition. She is the Irish representative on FIG Commission 2 and Chairs WG 2.2.

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